ERDC/CERL SR-07-24

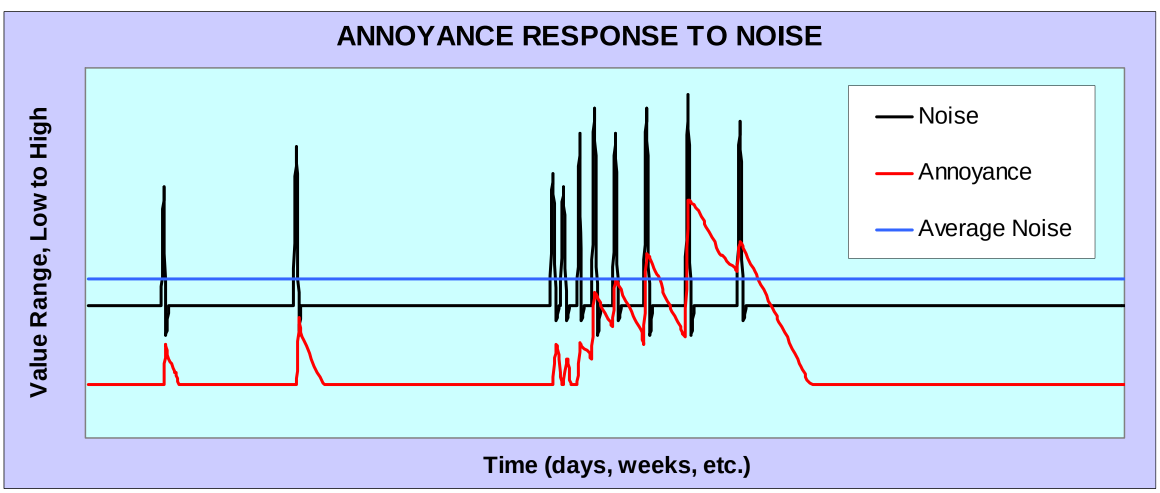
US Army Corps
of Engineers®
Engineer Research and
Development Center

An Investigation of Community Attitudes Toward Blast Noise:

Methodology

Larry L. Pater, Edward T. Nykaza, George Luz, Anthony Atchley,
Kathleen Hodgdon, Robert Baumgartner, and Pamela Rathbun

October 2007



Construction Engineering
Research Laboratory

ERDC/CERL SR-07-24
October 2007

An Investigation of Community Attitudes Toward Blast Noise:

Methodology

Larry Pater and Edward T. Nykaza
Construction Engineering Research Laboratory
U.S. Army Engineer Research and Development Center
2902 Newmark Dr.
Champaign,IL 61822-1076

George Luz
Luz Social and Environmental Associates
4910 Crowson Ave
Baltimore, MD 21212

Anthony Atchley
Graduate Program in Acoustics
The Pennsylvania State University
217 Applied Science Building
University Park, PA 16802

Kathleen Hodgdon
Applied Research Laboratory
216 Applied Research Laboratory
University Park, PA 16802

Robert Baumgartner and Pamela Rathbun
PA Government Services Inc.
6410 Enterprise Lane, Suite 300
Madison, WI 53719

Final report

Prepared for Engineer Research and Development Center
Construction Engineering Research Laboratory
2902 Newmark Dr.
Champaign, IL 61822-1076

Abstract: The military has determined that current blast noise impact assessment procedures do not fully meet the military's noise management needs. Noise impacts are almost universally assessed in terms of the response metric "annoyance" as predicted by a long-term average noise level metric. This has proven to be unsatisfactory for extremely variable impulsive military noise. Individual event noise levels from military testing and training activities can be loud enough to elicit negative community response, and even loud enough to exceed the human hearing damage threshold; yet when events are averaged over a year's time, the average level meets established acceptability criteria.

The objective of this project is to provide a research methodology for improving the current human response to blast noise assessment procedures. More specifically, this report outlines an approach to enhance understanding of human response to blast noise, and to determine a methodology to accurately predict human response to impulsive military noise. This methodology will provide reliable and practicable guidance for noise impact management decisions.

Contents

Preface

This report was prepared as a proposal to the Strategic Environmental Research and Development Program (SERDP) by Ed Nykaza and Larry Pater, Ecological Processes Branch (CN-N), Installations Division (CN), Construction Engineering Research Laboratory (CERL), U.S. Army Engineer Research and Development Center (ERDC), under the general supervision of Alan B. Anderson, Chief CN-N; Dr. John T. Bandy, Chief CN, and Dr. Ilker Adiguzel, Director, CERL. Technical supervision was provided by SERDP and their Scientific Advisor Board (SAB).

COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

Acronyms

ADNL	A-weighted Day-Night Average Sound Level
AEHA	U.S. Army Environmental Hygiene Agency
AERTA	Army Environmental Requirements and Technology Assessments
ANSI	American National Standards Institute
APG	Aberdeen Proving Ground
ARL	Applied Research Laboratory
ASA	Acoustical Society of America
ASEL	A-weighted sound exposure level
ATSC	Army Training Support Center
BRAC	Base Realignment and Closure
CDNL	C-weighted Day-Night Average Sound Level
CERL	Construction Engineering Research Laboratory
CHABA	Committee on Hearing, Bioacoustics, and Biomechanics for the National Academy of Sciences
CSEL	C-weighted Sound Exposure Level
dB**	Decibel
DNL**	Day-Night Average Sound Level
DNWG	Defense Noise working Group
DoD	Department of Defense
ERDC	United States Army Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
FAA	Federal Aviation Administration
Hz	Hertz
ICBEN	International Commission on the Biological Effects of Noise
IRB	Internal Review Board
ISO	International Organization for Standardization
JASA	Journal of the Acoustical Society of America
JLUS	Joint Land Use Study
LAeq24	A-weighted 24-hr Equivalent continuous level
LCeq24	C-weighted 24-hr Equivalent continuous level
LEQ**	Equivalent Continuous Noise Level
NAPS	Noise Assessment Prediction System
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NEPA	National Environmental Policy Act
NPS	National Park Service
OMB	Office of Management and Budget
OSHA	Occupational Safety and Health Administration
PAGS	PA Government Services Inc.
PCA	Principal Components Analysis
PDA	Personal digital assistant
PSF	Pound per square foot
PSU	Pennsylvania State University
RDD	Random-digit-dial

RMTK	Range Managers Toolkit
SE**	Sound Exposure
SEL**	Sound Exposure Level
SERDP	Strategic Environmental Research and Development Program
USACHPPM	United States Army Center for Health Promotion and Preventive Medicine
USAF	United States Air Force

**Sound Equations

$$\mathrm{dB} = 10\log(X/X_r);\ \text{where}$$

X = A quantity

X_r = A reference that normalizes X (has same units as X)

$$\mathrm{DNL\ (Daily)} = 10\log\left(\frac{1}{86400}\left(\int_{25200}^{79200}\frac{p^2(t)}{p_r^2} + 10\left(\int_{0}^{25200}\frac{p^2(t)}{p_r^2} + \int_{79200}^{86400}\frac{p^2(t)}{p_r^2}\right)\right)\right)dt;\ \text{where}$$

$p(t)$ = Instantaneous sound pressure (Pascals)

p_r = Reference pressure (20 μPascals for air)

t = Time (seconds)

$$\mathrm{Yearly\ DNL} = 10\log\left(\frac{1}{365}\sum_{i=1}^{365}(0.1\,(\mathrm{DNL}_i))\right)$$

$$\mathrm{LEQ} = 10\log\left(\frac{1}{T}\int_0^T\frac{p^2(t)}{p_r^2}\,dt\right);\ \text{where}$$

$p(t)$ = Instantaneous sound pressure (Pascals)

p_r = Reference pressure (20 μPascals for air)

t = Time (seconds)

T = Time period of measurement (seconds)

$$\mathrm{SE} = \int_0^T p^2(t)\,dt;\ \text{where}$$

$p(t)$ = Instantaneous sound pressure (Pascals)

t = Time (seconds)

T = Time period of measurement (seconds)

$$\mathrm{SEL} = 10\log\int_0^T\frac{p^2(t)}{p_r^2}\,dt;\ \text{where}$$

$p(t)$ = Instantaneous sound pressure (Pascals)

p_r = Reference pressure (20 μPa for air)

t = Time (seconds)

T = Time period of measurement (seconds)

1 Introduction

Background

The military has determined that current blast noise impact assessment procedures do not fully meet the military's noise management needs. Noise impacts are almost universally assessed in terms of the response metric "annoyance" as predicted by a long-term average noise level metric. This has proven to be unsatisfactory for extremely variable impulsive military noise. Individual event noise levels from military testing and training activities can be loud enough to elicit negative community response, and even loud enough to exceed the human hearing damage threshold; yet when events are averaged over a year's time, the average level meets established acceptability criteria. For example, land developers could use the military's own noise level criteria to choose building sites that appear to be in minimal noise impact areas. However, because the current criteria does not show the true impact of individual blast events, building in these areas will undoubtedly result in future noise problems. Moreover, citizens and decisionmakers find average noise level metrics to be confusing and irrelevant. Department of Defense (DoD) stakeholders recently adopted a revised interim methodology: average level criteria are supplemented by individual event peak noise level criteria that indicate noise complaint risk. The reason this is an interim method is because single event criteria do not account for aspects such as number and timing of noise events, and it is not known if complaints are a valid indicator of community attitude.

Adequate methods are needed to assess and predict community reaction to high-energy impulsive military noise, to preserve sustainable military training and testing capability, to maintain combat readiness, and to minimize noise impacts on residents of installations and nearby communities in the interest of public welfare.

Objective

The objective of this research is to enhance understanding of human response to blast noise, and to determine a methodology to accurately predict human response to impulsive military noise. This methodology will provide reliable and practicable guidance for noise impact management

decisions. The goal will be met by achieving the following specific objectives:

- The primary objective is to determine dose-response and acceptability criteria that can be universally applied, at least throughout the United States.
- Determine dose-response functional relationships between selected stimulus metrics and response metrics, and clarify the degree of correspondence among noise complaints, annoyance, and public reactions to blast noise.
- Determine stimulus and response metrics acceptability criteria that can be used to protect military training and testing capability and minimize noise impacts on residents of military installations and adjacent communities.

Approach

Using stimulus metrics and response metrics that are appropriate for variable high-energy impulsive noise, this research will establish dose-response cause-and-effect relationships between noise stimuli and human response. These relationships will supplement those currently used, i.e., long-term annoyance and complaints.

Military impulse noise levels are highly variable because of weather effects on propagation; therefore, this research will measure each noise event for which response is measured, to minimize the variance of the dynamic functional relation between stimulus and response. This research will examine the correlation between annoyance and complaints and will also establish acceptability criteria for noise metric values, to serve as guidelines for noise management decisions. The research project is divided into several distinct research protocols, which are described in Research Protocols, page 14. DoD stakeholders will be consulted and apprised regarding plans, progress, and results.

This project is a comprehensive interdisciplinary investigation that will be executed by a team of sociologists, acousticians, a psychologist, and a psychoacoustician, all of whom are experienced in acoustics and, in particular, noise response research. Researchers are drawn from the following organizations: United States Army Engineer Research and Development Center-Construction Engineering Research Laboratory (ERDC-CERL), Pennsylvania State University (PSU) Graduate Program in Acoustics,

Navy/PSU-affiliated Applied Research Laboratory (ARL), and PA Government Services Inc. (PAGS).

The research project is divided into several distinct protocols to accomplish the objectives. The protocols include (1) personal interviews with residents who experience weapons blast noise to define the range of response descriptors, (2) in situ studies with residents who experience blast noise to measure near real-time in-home responses, (3) general surveys with community members who experience blast noise to measure community response and changes in community response over time, and (4) noise complaint event level criteria to determine the relationship between complaints and annoyance.

The intent is to start with individuals (personal interviews and in situ studies), compare findings across a several communities (general surveys and complaint surveys), and compare findings across installations. This process will allow identification of trends that can be generalized to exposure-response relationships on a national level.

Mode of Technology Transfer

The knowledge gained from this research will establish impact assessment methodologies and impulse noise acceptability criteria that will serve as guidelines to protect both military training capability and public welfare.

The results will be published in refereed journal articles. Researchers anticipate that these guidelines will be incorporated into applicable military and civilian regulations and standards. Results will also be provided directly to DoD stakeholders, particularly the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM), the Army Training Support Center (ATSC), and the Defense Noise Working Group (DNWG), for adoption into noise impact assessment and management procedures.

Additionally, this report will be made accessible through the World Wide Web (WWW) at URL http://www.cecer.army.mil

2 Technical Approach

This chapter is organized into three sections: general background, impulsive noise assessment methods, and review of previous military impulse noise research. Facts and information that influenced the design of the current research approach are reviewed. Serious flaws in current high-energy impulsive noise assessment methodologies are pointed out, and needed improvements in assessment methodology are highlighted.

Background

Blast noise is emitted by projectiles, explosives, and artillery and armor muzzle blast. These noise events are of short duration, typically a fraction of a second. The energy spectrum is rather broad, with acoustical energy typically concentrated at frequencies between 1 and 100 hertz (Hz). High-energy impulsive noise from military weapons can be very loud at distances of many tens of kilometers.

Ground-to-ground propagation of blast noise is strongly influenced by atmospheric temperature and wind structure. Experiments have shown variation of more than 50 decibels (dB) (Schomer et al. 1978) in received noise levels, all factors held constant except for weather. A change of 50 dB covers a range from barely noticeable to extremely loud, and implies a standard deviation in received noise level on the order of 8 dB due to changes in atmospheric meteorological parameters that influence sound propagation. To avoid disastrously large variance and uncertainty in dose-response data, research that aspires to meaningfully determine the dynamic link between stimulus and response must accurately measure the stimulus metric value of each noise event used to judge human response. In some previous high-energy impulsive noise assessment studies, average expected noise levels were predicted or calculated rather than experimentally measured (Schomer 1985). It might be tempting to simplify study protocols and reduce costs by using noise prediction software such as BNOISE2™ (developed by ERDC-CERL) to calculate noise levels, rather than measure them. This is inadequate because BNOISE2™ predicts noise levels statistically; actual event levels may differ from predicted values by as much as 25 dB in either direction from the median level, whereas a change in noise level of 5 dB can result in a significant change in response.

Impulsive Noise Assessment Methods

Broadly speaking, two basic methodologies have been used to assess and manage military impulsive noise. One measures community reaction in terms of "annoyance" (the response metric) correlated to long-term-average noise (the stimulus metric). The other uses noise complaints risk (the response metric) correlated to single-event peak pressure (the stimulus metric). Both methods are reviewed below.

The annoyance/long-term average noise assessment method is based on assessment procedures that were established for transportation. Noise impact from transportation noise sources such as aircraft and road traffic is assessed by virtually everyone, including the military, in terms of annoyance as predicted by long-term average noise. Schultz (1978), in a seminal paper, published a dose-response relationship for transportation noises based on data obtained by many researchers. This approach has been adopted internationally for virtually all types of noise, including high-energy impulsive noise, as described in American National Standards Institute (ANSI) 12.9Pt.4 and International Organization for Standardization (ISO) 1996.

The response metric for this assessment method is the percentage of the population that is "highly annoyed," measured via a social survey. The stimulus metric for this assessment method averages the sound exposure (SE) (defined as the time integral of pressure squared) over the assessment period, which is typically 1 year. The method, applied to blast noise (Committee on Hearing, Bioacoustics and Biomechanics [CHABA] 1981) and later modified (CHABA 1996), became official Army policy as described in Chapter 7 of Army Regulation 200-1, version dated 1997. An average noise level of 62 dB C-weighted Day-Night Level (CDNL), which is taken to predict that 13 percent of the population would be highly annoyed, was deemed acceptable for all land uses including schools, hospitals, and residences.

Long-term-average noise level does not adequately guide land use. As an example, 100 events of 142 dB peak pressure level yield an annualized CDNL of 62 dB, which is supposedly suitable for all land uses. However, a peak level of 142 dB is so loud that it would almost certainly cause a strong negative public reaction, and in fact exceeds the 140 dB threshold for human hearing damage (Military Standard [MIL-STD]-1474D; Occupational Safety and Health Administration [OSHA] 1983). Land developers could

use the military's own noise criteria to select building sites that appear to be in minimal noise impact areas. However, because the current criteria does not show the true impact of individual blast events, building in these areas will undoubtedly result in future noise problems. Average noise levels provide no indication of the loudness of individual events to which citizens are exposed. Citizens and military decisionmakers find average noise level metrics to be confusing, irrelevant, and disingenuous for blast noise. At public hearings, citizens consistently ask what noise levels they will hear (Wm. Russell, Program Manager, USACHPPM, pers. comm.). Experience at installations strongly indicates that the public adversely reacts, as evidenced by complaints, to the noise level of specific events rather than only the average noise level of relatively infrequent blast noise events.

Another difficulty is that impact assessment results depend strongly on the selection of the time period over which the noise is averaged. The method ignores any effect of the timing of noise events; there is no difference between 10,000 noise events spread over 1 year or all occurring in 1 day. An underlying assumption behind this method is the "equal energy hypothesis," which states that the noise is accounted for by averaging the total SE over the assessment period, regardless of the magnitude of any individual noise event. This means, for example, that the effect of 1000 events of a given sound exposure level (SEL) is taken to be the same as that of 1 event containing 1000 times as much sound exposure (30 dB greater SEL). An example of this paradigm is given in Figure 1.

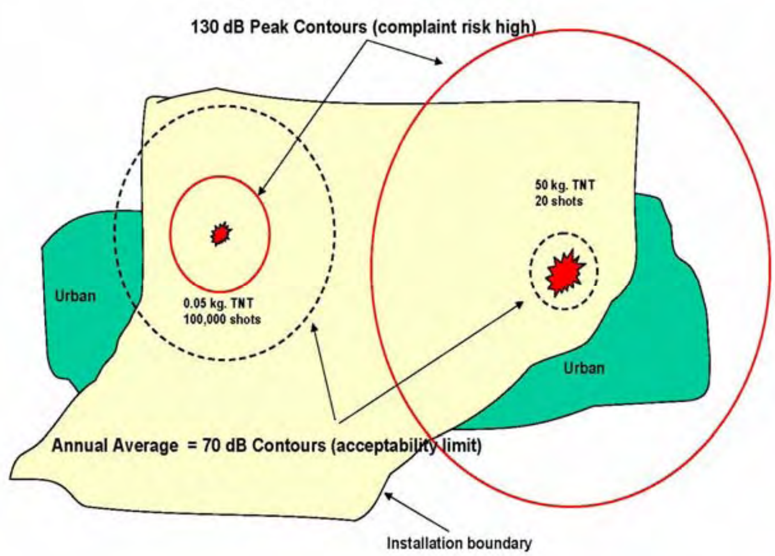


Figure 1. Paradigm with current blast noise assessment procedures.

ANSI S12.9-2005/Part 4 has for many years been strongly oriented to traditional assessment of high-energy impulsive noise based on long-term-average CDNL noise level. The 2005 revision of the standard recognizes the problems of the equal energy hypothesis for high-energy blast noise, by virtue of adopting level-dependent metric adjustments that are used to convert event CSEL (C-weighted SEL) values into event ASEL (A-weighted SEL) values that are used in calculating the long-term-average noise level, as presented in Annex B of the Standard. Further, the standard for the first time includes discussion of complaint response to discrete noise events, specifically in clauses 1.1, 1.6, 8.2, and a new informative annex dealing with military high-energy impulsive noise. The standard did not go further because of a lack of research results, which this proposed research project will provide.

The second type of impulsive noise assessment method predicts complaint risk as a function of event noise level. At installations, noise impact is often managed based on complaints. Complaints received from a variety of citizens and locations (as opposed to a small number of chronic complainers) are taken as an indication of a problem that can be expected to escalate into more aggressive attempts to curtail the noisy activity. A set of blast noise complaint risk criteria was developed by the Navy (Pater 1976) to guide decisions balancing the risk of noise complaints against the cost of canceling the training or testing activity. These criteria state that complaint risk is very low for peak levels below 115 dB, that risk increases as peak levels escalate, and that complaint risk is high at peak levels of 130 dB and higher. These complaint risk criteria were recently adopted by the Army as the best available interim blast noise management guidance (Army Regulation [AR] 200-1, 2007).

A possible objection to complaint risk criteria is that one might expect a great deal of variation in individual response, presumably the result of many factors such as socio-economic status and philosophical opinions. This would surely be a complicating factor in developing a dose-response relation for response to discrete events. There is evidence that such a relation may however be possible for blast noise. Noise complaint risk guidelines virtually identical to those proposed by Pater (1976) have been independently developed by Aberdeen Proving Ground, MD (USACHPPM 1994), the United Kingdom (Geoff Kerry, University of Salford, pers. comm.), Germany (Karl Hirsch, Institut fur Larmschultz, Dusseldorf,

Germany, pers. comm.), and for sonic booms (Micah Downing, Blue Ridge Research, pers. comm.).

A discrete noise event metric has several potential advantages; (1) it can be directly measured, (2) it is easy to explain to decisionmakers and the public, and (3) it facilitates concrete noise impact reduction guidelines. Impact assessment computational labor is reduced compared to average noise methods, and the results are less dependent on having accurate data regarding the number of noise events (such data from installations are notoriously unreliable). However, it has not been proven that noise complaints are an accurate measure of community response; much remains unknown regarding complaints. The criteria in the previous paragraph are lacking in that they are based on experience at installations rather than peer-reviewed formal research. At the present stage of development, the discrete noise event method provides no information regarding the effect of factors such as the number of noise events in a given time period, the elapsed time since the last bout of noisy events, or population demographics.

The Army has judged the average noise methodology to be unsatisfactory for impulsive military noise. DoD stakeholders recently adopted a revised interim methodology that supplements "annoyance correlated to average noise level" with "complaint risk correlated with event noise level" to assess impulsive noise impact (AR 200-1 2007). DoD stakeholders have endorsed this research proposal as the means to achieve improved assessment procedures.

One of the important justifications for the research proposed in this report is that the technology of blast noise measurement has exceeded the psychoacoustic knowledge for interpreting those measurements. This situation stands in contrast to the technological environment of the mid-1970's, when the U.S. Environmental Protection Agency recommended that all Federal agencies adopt some variant of day-night average sound level (DNL) to assess all types of intrusive noise exposures. At that time, there was a more sophisticated psychoacoustic approach for assessing the annoyance of aircraft noise than is afforded by DNL. That approach, which combined the loudness, duration, and tonality of aircraft flyovers into a single annoyance prediction, was based on the work of S.S. Stevens (ISO 532A). The problem, however, was that the only way to conduct the analysis was to tape record the flyover and conduct a lengthy analysis in the

laboratory. Clearly, such a laborious procedure was not economically feasible for the day-to-day management of environmental noise, so the superior psychoacoustic approach was pushed aside by a more economical approach – periodic sampling of the A-weighted noise level with arithmetic summary of the average acoustic energy in the sample (otherwise known as the equivalent level or LEQ). During the 1970's, measurement of blast noise was even more difficult than the measurement of aircraft noise, and, in an attempt to find a measure available to enforcement authorities at all levels of government, the National Academy of Sciences-National Research Council Committee on Hearing, Bioacoustics and Biomechanics recommended the C-weighted sound exposure level.

Review of Previous Military Impulse Noise Research

Review of the literature reveals a major difference between research that supports the transportation assessment procedure and the high-energy impulsive noise assessment procedure. The transportation assessment procedure is built on a large number of social surveys and research studies (Schultz 1978), while the high-energy impulsive noise assessment procedure is primarily based on five studies (CHABA 1996). Important details of the technical data and research conclusions of those impulsive noise studies are presented in the Appendix. This review led to the following conclusions.

1. All previous studies looked for correlation between annual average noise level and a one-time measurement of community response. This cannot account for the possibility that response may change as a function of the changing noise environment on a time scale shorter than the assessment period, which is recommended to be 1 year.

2. Predicted, rather than measured, noise levels were relied on in all of the previous blast assessment research. Further, the predictions were made without meteorological information that would enable accurate predictions (recall that weather can cause a total variation of as much as 50 dB in received noise level). In one study, actual measurements were made but were measured only for approximately 25 days at each of the study areas after the study was completed (Schomer 1981). Given the huge influence of weather on received noise level, there is no assurance that the same types and amount of blast noise events occurred during those 25 days as occurred during the time before and during the social survey.

3. In another study, actual noise measurements were made during the 6 months prior to the social survey, but were not used because the levels recorded did not show the correlation that was expected with the percent highly annoyed response metric (Schomer 1985).

4. In all of the reviewed studies, percent highly annoyed was assumed to be the appropriate response metric. Work done for the National Park Service and the U.S. Air Force (USAF) has identified insufficiencies in traditional psychoacoustic response metrics such as "annoyance" (Baumgartner 1999). The National Park Service has considered annoyance and interference metrics as criteria for managing the air space above national park visitor areas (Miller et al. 1999).

5. Review and consideration of blast noise and sonic boom studies suggested that the following acoustic and non-acoustic factors should be considered and evaluated during the proposed research:
   - Startle
   - Habituation
   - House vibration and rattle
   - Fear of damage from the source
   - Belief that one should complain about the source
   - Noise sensitivity
   - Belief that more can be done to reduce the noise impact
   - Interference with various activities.

3 Methods

Many investigations of noise impact have studied the relation between pre-selected stimulus and response metrics. This proposed research adopts a more ambitious but potentially far more rewarding paradigm. It will objectively determine, rather than assume, the best metrics to describe both stimulus and response. This will be accomplished by identifying the language or descriptors that residents living near military installations use to describe their reaction/opinion of blast noise via personal interview protocol and by identifying the aspects of the stimulus that residents react to via the in situ protocol. Potential stimulus and response metrics identified from these protocols will be added to the existing list of candidate metrics and will be included in the surveys. The list of candidate stimulus and response metrics is given below and is based on recommendations made by the International Commission on the Biological Effects of Noise (ICBEN) (Fields et al. 2001), ANSI and ISO standards, and previous human response to noise studies.

Response Metrics

A suitable response metric for human response to highly variable military high-energy impulsive noise must be a measurable quantity, must be a dynamic measure (i.e., able to capture changing response to changes in noise environment and other factors), and must capture the aspects of human response that have meaning to the exposed public, to enable determination of impact on the public and resultant impact on military capability. The protocols will include the widely used annoyance metric as defined by ICBEN and will include noise complaints received by specified organizations.

To advance the state of knowledge, the researchers will make an objective determination of one or more improved response metrics via personal interview protocol and will examine the correlation between annoyance and complaints. They will also test the hypothesis that the response might vary over time as a result of the variation in received noise levels due to weather conditions and operational schedules. Response could also vary if the community had not experienced the noise recently, or conversely had become habituated to the noise, or if other events cause community attitude toward the noise to change.

Stimulus Metrics

A suitable stimulus metric characterizes aspects of the stimulus that elicit human response, including the resulting structural vibration and rattle. Many factors enter into the functional dose-response relationship (such as the number and timing of noise events) and it is possible that different metrics may be needed to guide short-term operational and long-term land use decisions. To advance the state of knowledge, researchers will record the waveform and calculate metric values for every event that is used in the protocols. Modern automated computer-based calculation of several metrics, and examination of degree of correlation among them, makes this approach quite feasible.

Below is a list of candidate metrics used in various impulsive noise studies and standards (ANSI 12.9 Pt.4, 2005; Borsky 1965; CHABA 1996; Fields 1997; ISO 1996:1-2003; ISO 226-1987; ISO 532A; ISO 532B; Izumi 1977; Luz et al. 1983; MIL-STD-1474D 1997; Nykaza et al. 2006; Pater 1976; Schomer 1985; Schultz 1978).

- Peak sound pressure level (A, C, and flat frequency weighting filter functions).
- Average level LEQ (A, C, and flat) over a specified time interval.
- Sound exposure level (A, C, and flat).
- Exponential time-weighted sound level (slow, fast, impulse), for historical comparison.
- Loudness.

These metrics will be the main focus and are justified because they are the best available knowledge and capture the aspects of the stimulus that have had the most success in predicting the response, have historical significance, and follow the precedence given in the cited references. However, other metrics may be considered as deemed appropriate during the study to maintain the objective, unbiased approach of this proposal. This is especially important given the recent changes in AR-200-1 and ANSI 12.9 Pt.4, 2005, to include the shift of importance from yearly-averaged noise levels to single event levels.

Dose-response, Statistical Design, and Acceptability Criteria

Researchers will explore dose-response cause-and-effect functional relationships between selected stimulus metrics and response metrics for each

of the applicable protocols (described below). The predictor variables are based on measurements that are both quantitative (stimulus metrics) and qualitative (most response metrics). Factor analyses (e.g., principal component analysis [PCA]), will be utilized to reduce the number of variables and identify relationships between variables. When the predictor variables to be compared are all quantitative, a multiple regression analysis may be conducted. If the predictors are all qualitative, an analysis of variance will be performed. If some predictors are quantitative and some qualitative, an analysis of covariance will be used. The multiple regression analysis may be used to assess relationships between data sets and the analysis of variance, or covariance may be used to assess the differences between the data set. For ordinal subjective data, a nonparametric test, such as the Spearman Rank Correlation Coefficient will be used to analyze relationships between stimulus and response metrics.

The list of stimulus and response metrics above should not imply that all metrics will illuminate the factors that are pertinent to annoyance. It is the intent to consider a wide range of acoustic factors that could elicit a subjective response and annoyance. The best metrics will then be run on a larger dataset and correlated with annoyance ratings. This effort does acknowledge and build on the research conducted during the 1970's (Shultz 1978, CHABA 1996). That research was extensive and impressive, and is of great value to the current effort.

The acceptability criteria or threshold limit values identified from collectively examining results from each protocol will provide reliable and practicable guidance for noise impact management decisions, which will ultimately provide a means to sustain operational capability. The dose-response relations and acceptability criteria will be used to guide near-real-time and long-term noise management decisions by military commanders and range managers. That is, short-term risk assessments can be made to guide decisions to balance program delays against negative community response and long term planning decisions can be guided by statistical expectations of variance in propagation conditions and thus of risk of adverse community reaction. Findings from this research can be applied with existing DoD tools such as Range Managers Toolkit (RMTK) and BNOISE2.

Research Protocols

The research project is divided into several distinct protocols to achieve the research objectives. The research protocols are described below in detail.

Researchers will obtain Office of Management and Budget (OMB) approval before conducting any research that involves public surveys. The research protocols include: (1) personal interviews with residents who experience weapons blast noise to define the range of response descriptors, (2) in situ studies with residents who experience blast noise to measure near real-time in-home responses, (3) general surveys with community members who experience blast noise to measure community response and changes in community response over time, and (4) noise complaint event level criteria to determine the relationship between complaints and annoyance.

The intent is to start with individuals (personal interviews and in situ studies), compare findings across several communities (general surveys and complaint surveys), and compare findings across installations. This will allow identification of trends that can be generalized to exposure-response relationships on a national level.

OMB Approval

Some of the research protocols described below involve collection of data from the public and will require OMB approval of the data collection plan. Currently, it takes the OMB approximately 6 to 9 months to approve of a data collection plan. This process includes the following steps:

- Prepare the Information Collection document according to OMB specifications;
- Develop the required Paperwork Reduction Act supporting statements;
- Publish a notice in the Federal Register providing a chance for any interested individuals to comment on the proposed information collection within 60 days;
- Prepare the final Paperwork Reduction Act submission, including any public comments received, to OMB;
- Receive OMB approval or disapproval for the information collection.

Personal Interview Protocol

Qualitative personal interviews with community residents will identify response metrics that have meaning to the population of interest and can provide a more complete understanding of community impact. A total of 10 to 20 qualitative personal interviews will be conducted at each installation evaluated with residents who live in areas that are typically exposed to high-energy impulsive noise. Detailed interviews will be transcribed verbatim and evaluated successively to code the input either manually or using an analysis software such as NVivo (QSR International). The individual interviews will then be compared for common observations, terminology, and types of complaints. A comprehensive analysis of these qualitative interviews will define a range of response descriptors that can be added to the list of candidate response metrics to be tested in the In-Situ and General Survey protocols. The process provides a more comprehensive and insightful assessment of the community impact.

It is common practice in survey research to first use personal interview protocols to allow the population of interest to identify, in everyday language, a range of appropriate response descriptors. Work done for the National Park Service and the USAF has identified insufficiencies in some of the traditional psychoacoustic response metrics such as "annoyance" (Baumgartner 1999).

Alternative response metrics were tested in a study of the Impact of Aircraft Overflights on park visitors for the National Park Service in the 1990's. Respondents for a dose-response study reported higher levels of impact from aircraft overflights for the response measure "interference with the appreciation of natural quiet and the sounds of nature ..." than the traditional annoyance response measures. Qualitative research for the USAF also indicated that visitors interpret the two response measures differently. In-depth interviews with visitors who had experienced aircraft overflights indicated that the term 'interference' implies that one is prevented from doing something, or in the case of park visitors seeking solitude, distracted from a task or activity they were pursuing. On the other hand, the term 'annoyance' indicates a physical or emotional response to noise. Based on this analysis, the National Park Service has considered both types of response measures in their dose-response models and in managing the air space above national park visitor areas (Miller et al. 1999).

In-Situ Protocol

The In-Situ protocol will examine how humans respond to individual blast events in near real-time as a part of their typical experience. This will provide the data necessary to determine which aspects of the noise correlate with human response. Until this is done, it will be impossible to determine exactly which aspects of the noise humans are reacting to. It is necessary to determine which aspects and noise metrics should be measured and predicted by installations to guide their long and short term operations.

A cross-sectional sample of residents who live near military installations and are typically exposed to blast noise will be selected to participate in this protocol. Microphones and accelerometers will be set up outside and inside residents' homes to document the stimulus (blast noise, vibration, rattle); computers, personal digital assistants (PDAs), or cell phones will be used to record the response. Subjects will report via questionnaire their reactions to each noticeable blast event. Response questionnaires will be designed according to the findings of the personal interview protocol and will mirror questions asked in the general survey protocol.

This protocol will be conducted in the vicinity of two training installations that produce blast noise and that vary in population demographics and terrain. At each installation, the protocol will be conducted over a 9- to 12-month period, involving approximately 25 subjects at each site, to capture a sufficient data set and also to sample the variation in received waveform due to seasonal weather changes.

Researchers have identified installations as potential study sites and have begun preliminary discussions with installation key personnel. The strength of the In-Situ protocol is the ability to gather detailed data regarding the variation of subject response to variable stimulus levels (dose-response functionality). A potential weakness is that the subjects are aware that they are participating in a study. This study will incorporate research procedures commonly used in diary studies to mitigate the extent to which the increased awareness and attention to blast events may skew their responses.

General Survey Protocol

The General Survey protocol is different from previous surveys because better measurements of the noise environment will be made and correlated to several measurements of response via social survey. Recall that previous blast noise surveys correlated a single measurement of the average noise level for an entire year with a spot measurement of annoyance. A review of previous human response to impulsive noise studies is given in the Appendix. Two conclusions can be drawn from an objective review of these studies: (1) the studies failed to account for the influence of individual noise event levels, and often the measures of yearly average noise levels are predicted rather than measured; (2) the studies assumed that community annoyance does not change as a function of time or a function of short-term changes in noise environment. It is not surprising that the correlation between yearly averaged noise levels and a one-time measure of annoyance is quite low. Such research is inherently and unavoidably unable to detect the dynamic relationship between noise level and annoyance response. It also implicitly and tacitly assumes that annoyance does not vary with short-term variance in noise level, which is an unproven hypothesis that potentially invalidates previous studies of human response to high-energy blast noise, since the measurement of response took place at a time of unknown stimulus noise level.

The General Survey protocol utilizes a questionnaire to determine community response to the noise stimulus. It will be administered several times in coordination with the In-Situ protocol, but will sample a different set of subjects in the population. The questionnaire will be crafted in such a way that the subjects will not be aware that the objective of the questionnaire is to determine noise response and will be designed according to ICBEN recommendations (Fields et al. 2001). Actual noise level history will be available from measurements made as part of the In-Situ protocol. Previous studies typically did not obtain such measurements, but relied on computer model predictions of unreliable accuracy because of inadequate meteorological information (Schomer 1981, Schomer 1985, and Rylander and Lundquist 1996). In any functional dose-response investigation, actual measurements are superior to predicted measurements because they eliminate the uncertainty inherent in predictions of highly variable noise events.

Professional interviewers will conduct in-person interviews at randomly selected households in the study areas. The advantages of this approach,

in comparison to telephone surveys, are that all households are eligible for selection in the sample. Also, the interviewer is better able to gain cooperation and produce a higher response rate, the survey questionnaire can be longer with less risk of drop-offs in the middle of the interview, and the interviewer can control the flow of the interview and provide stimuli or aids (such as response cards) as appropriate during the survey. A disadvantage of this approach is typically high cost. However, in this project, the cost-effectiveness of in-person household interviews and telephone interviews are quite comparable. For telephone surveys, it is difficult to get full coverage of all households and individuals in the study area and responses rates will be significantly lower. Telephone surveys rely on a listing of telephone numbers. Random-digit-dial (RDD) procedures are not efficient for this purpose, because the areas used to assign phone numbers will not be consistent with the study areas and additional screening would be required to identify eligible households. In lieu of RDD procedures, telephone company listings, city directories, and the like could be used to develop the sample frame (list of telephone numbers). However, with all of these published sources, the incidence of unlisted and do-not-call numbers is high (and increasing over time) in many communities. The telephone survey approach would most likely require additional follow-ups (either by mail or door-to-door) to attempt to reach those households with unlisted numbers to ensure a representative sample of survey respondents. This additional effort would raise the cost of telephone interviews considerably and introduce potential data collection mode effects into the survey data.

For these reasons, researchers propose to use a door-to-door in-person interview for the General Surveys. For each community, the survey will include two different samples of households:

- A cross-sectional representative sample to gauge the level of response among community residents at each point in time, and
- A panel sample of households (the same households surveyed each time) to enable analysis of the factors that influence change in household response over time.

The survey will be conducted at approximately 4-month intervals with the representative cross-sectional samples of households, and at approximately 6-month intervals with the panel sample of households. Table 1 shows the sample design for the General Survey for each community:

Table 1. Sample design for the General Survey for each community.

	Month 3	Month 7	Month 11
Panel Survey	175 households		175 households (as many of the original 175 as possible)
Cross-sectional Sample	175 households	175 households	175 households

After the initial survey wave (Month 3), one-half of the 350 responding households will be randomly selected and assigned to the panel sample. The panel sample of 175 households will be re-surveyed in Month 11. The panel sample will not be surveyed in Month 7 to avoid sensitizing respondents to noise impacts by surveying them too frequently. The purpose of a panel survey (also frequently called a longitudinal survey) is to measure changes in awareness, attitudes, or reported impacts at the individual household level. Because data are collected from the same households at two different points in time, an analysis of the magnitude of the changes, as well as the factors associated with the changes in household response, can be conducted.

The representative cross-sectional sample will include a different random sample of 175 households at each of the three survey waves. The cross-sectional sample will provide data on the levels of awareness, attitudes, and reported impacts at the community level. Three cross-sectional samples will be conducted in each community at 4-month intervals to provide a more frequent measure of the community-level noise impacts.

The demographic and socioeconomic characteristics of the sample of residents who are surveyed will be compared to the characteristics for the U.S. Census data block in which the measurement area is located. In cases where the characteristics of the sample of survey respondents differs from the characteristics of the known population of the study area, sample weights can be used to statistically adjust the characteristics of the sample of survey respondents and attempt to mitigate any coverage bias. A major factor in the choice of study sites is a sufficiently large number of households exposed to blast noise events.

Study Region

The Study Region example presented in Figure 2 illustrates how the noise environment for the In-Situ, General Survey, and Complaint Study proto-

cols will be determined. Researchers will record noise events at locations strategically distributed throughout sub-regions that make up the Study Region. For the In-Situ studies, some of the measurement sites will be at the homes of the study participants.

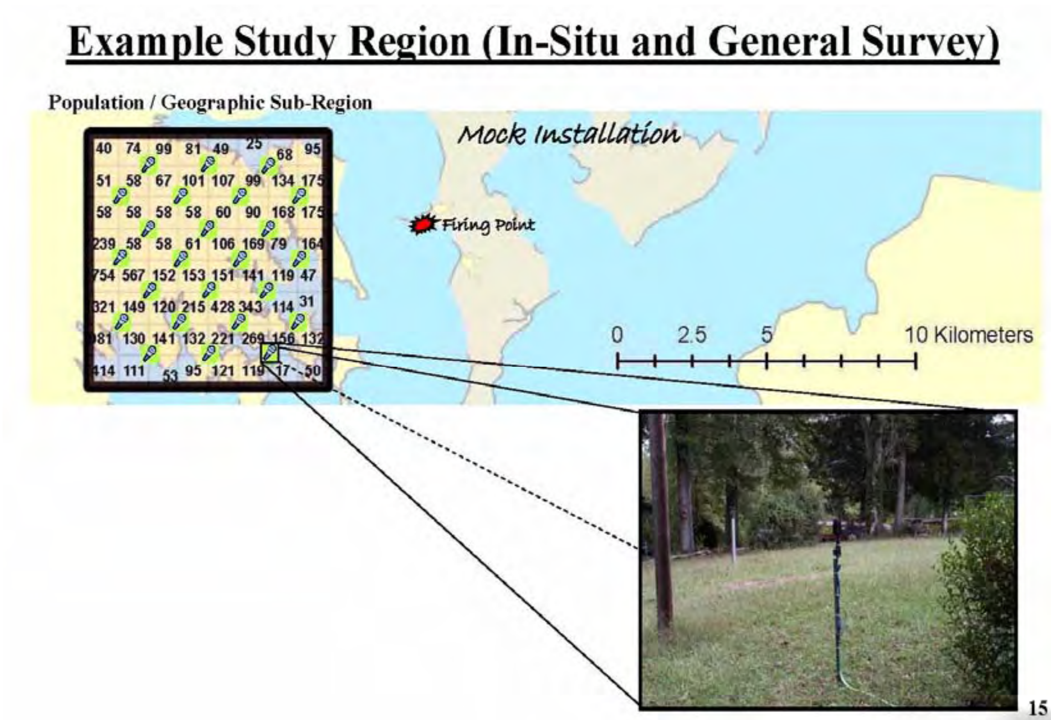


Figure 2. Study region example.

The General Survey and In-Situ protocols will take place simultaneously and the noise monitors set up at each participant's house in the In-Situ protocol can be used to describe the noise environment of a larger area or referred to as the study area in this research plan. The general survey will take place within the study area so a direct correlation between the stimulus (noise events) and response to survey questions can be made. In summary, noise monitors at installations are typically spread out and measure only peak noise level and therefore, cannot solely be relied upon for conducting the research outlined in this proposal. As a result, other instruments will be used to conduct the research.

Complaint Survey Protocol

The complaint survey will rely on measured noise levels from 44 noise monitors that will be set up in various communities surrounding the Aberdeen Proving Ground (APG), Maryland. Predictive models will be used to extrapolate and supplement noise monitor measurements to intermedi-

ate locations, which may be needed if complaints do not occur near one or more of the noise monitors. This is facilitated by the availability of atmospheric meteorological profiles at APG. While it would be ideal to have measured noise levels for each response as in the case of the In-Situ protocol, it is not technically or economically feasible to do so. On the other hand, the protocol for the complaint survey is superior to previous studies (see the Appendix) because each and every noise event will be measured.

The new Army noise requirements in AR 200-1 state that using complaint risk criteria to supplement annoyance correlated to average noise level is an interim procedure to be used until better guidance is available. It is inadequate because the relationship between complaint response and community annoyance is unknown. One of the objectives of this proposal is to clarify the degree of correspondence among noise complaints, annoyance, and public reactions to blast noise.

Results of this protocol will be crucial in illuminating the correlation between community response and complaints. This will help determine how much "weight" complaints should be given in noise impact management practice. Complaints are taken very seriously at installations; testing and training curfews and restrictions are often driven by noise complaints. Without reliable guidance, these restrictions may needlessly impair mission capability and/or result in failure to achieve noise management objectives.

It is unclear whether individual complainants are representative of the general community response to the stimulus. It is possible that unnecessary testing and training restrictions have been implemented because of the complaints of a few noise-sensitive complainants. A recent study conducted by one of the authors of this proposal (Nykaza et al. 2006) found that unnecessary and improper nighttime training restrictions were imposed at an installation. On the other hand, complaints may be in some way a useful indicator of the general community response. The relationship between complaints and community response will be tested by surveying residents in the vicinity of recent noise complaints within a week of a complaint. The survey questions designed in the General Survey protocol will be used for uniformity between tests, and the surveying area will include a random sample of residents living within the vicinity of complainants.

An understanding of where in the response spectrum complainers fall would be very useful information. Accepted aircraft noise criteria stipulate that it is acceptable for about 13 percent of the population to be highly annoyed. For example, if it is determined that individual complainants are outliers and do not act as a surrogate measure of the general community annoyance, then it may follow that complaints should receive less emphasis than they often do at installations.

4 Summary

The objective of this project is to provide a research methodology for improving the current human response to blast noise assessment procedures. The knowledge gained from this research will establish impact assessment methodologies and impulse noise acceptability criteria that will serve as guidelines to protect both military training capability and public welfare. As of May 2007 this research plan has been funded by the Strategic Environmental Research and Development Program, and is slated to begin February of 2008.

References

Cited

ANSI 12.9 Pt. 4, 2005. "American National Standard Quantities and Procedures for Description and Measurement of Environmental Sound – Part 4: Noise Assessment and Prediction of Long-Term Community Response," Acoustical Society of America, New York.

Army Regulation AR 200-1, 2007. "Environmental Protection and Enhancement-Chapter 7: Environmental Noise Management Program," 28 August 1997.

Baumgartner, R., 1999. "Respondents' interpretations of impact measures for dose-response studies," FICAN Symposium on the Preservation of Natural Quiet, 138th Meeting of the Acoustical Society of America, November 3, 1999, Columbus, OH.

Borsky, P. N., 1965. "Community Reactions to Sonic Booms in the Oklahoma City Area," AMRL-TR-65-37.

CHABA, 1981. "Assessment of Community response to High Energy Impulsive Sounds," Committee of Hearing, Bioacoustics and Biomechanics, National Research Council, Wash. D.C., National Academy Press.

CHABA, 1996. Fidel (editor), "Community Response to High-Energy Impulsive Sounds: An Assessment of the Field since 1981," Committee of Hearing, Bioacoustics and Biomechanics, National Research Council, Wash. D.C., National Academy Press.

Fields, J., C. Moulton, R. Baumgartner, and J. Thomas. 1994. "Residents' Reactions to Long-Term Sonic Boom Exposure: Preliminary Results." In Proceedings of the 1994 NASA Sonic Boom Conference, NASA Langley Research Center.

Fields, J. M., 1997. "Reaction of Residents to Long Term Sonic Boom Noise Environments," NASA Langley Research Center CR 20103, June 1997.

Fields, J. M., et al., 2001. "Standardized General-Purpose Noise Reaction Questions for Community Noise Surveys: Research and Recommendations," J. Sound and Vib., 242(4), 641-769.

Fields, J.M. and Powell, C.A. 1987. "Community reactions to helicopter noise: Results from an experimental study," J. Acoust. Soc. Am. 82(2). 479-493.

ISO 1996:1-2003. "Acoustics -- Description, measurement and assessment of environmental noise -- Part 1: Basic quantities and assessment procedures," International Standards Organization, November 2003.

ISO 226. (1987) Acoustics: Normal Equal-Loudness Contours (International Organization for Standardization, Geneva).

ISO 532A; ISO (1975) "Acoustics. Method for calculating loudness level. International Standard ISO 532 (1.ed.)", International Organisation for Standardisation.

ISO 532B; ISO (1975), "Acoustics Method for calculating loudness level. International Standard ISO 532 (1.ed.)", International Organisation for Standardisation.

Izumi, K., 1977. "Two experiments on the perceived noisiness of periodically intermittent sounds," Noise Control Engineering, 9, 16-23.

Luz, G.A, Raspet, R., and Schomer, P.D., 1983. "An Analysis of Community Complaints to Noise," J. Acoust. Soc. Am. 73(4).

Miller, N. P. et al., 1999. "Mitigating the Effects of Military Aircraft Overflights on Recreational Users of Parks," HMMH Report No. 294470.04, July 1999.

MIL-STD-1474D. Department of Defense Design Criteria Standard: Noise Limits, MIL-STD-1474D, 12 February 1997.

Nykaza, E. T., Pater, L. L., and Melton, R.H., 2006, "Sleep impacts of nighttime training noise from large weapons on residents living near a military installation," ERDC/CERL TR-06-21.

OSHA, 1983. Department of Labor Occupational Noise Exposure Standard, Code of Federal Regulations, Title 29, Chapter XVII, Part 1910, Subpart G, 36 FR 10466, May 29, 1971, Amended March 8, 1983. This standard is available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9735

Pater, L.L., 1976. "Noise Abatement Program for Explosive Operations at NSWC/DL," presented at the 17th Explosives Safety Seminar of the DOD Explosives Safety Board.

Rylander, R., and Björkman, M., 1988. "Maximum noise levels as indicators of biological effects," J. Sound and Vibration, 127, 555-563.

Rylander, R. and Lundquist, B., 1996. "Annoyance Caused by Noise from Heavy Weapon Shooting Ranges," Journal of Sound and Vibration 192(1), 199-206.

Schomer, P.D., 1981. "Community Reaction To Impulsive Noise-Initial Army Survey," CERL TR N-100.

Schomer, P.D., 1985. "Assessment of Community Reaction to Impulse Noise," J. Acoust. Soc. Am. 77(2).

Schomer, P.D., and Averbuch, A., 1989. "Indoor human response to blast sounds that generate rattle," J. Acoust. Soc. Am. 86(2), 665-673.

Schomer, P.D. Goff, R.J., and Little, L.M., 1978. "Statistics of amplitude and spectrum of blasts propagated in the atmosphere," Journal of the Acoustical Society of America, 63(5), 1431-1443.

Schultz, T., 1978. "Syntheses of Social Surveys on Noise Annoyance," .Journal of the Acoustical Society of America, Volume 62, pages 377-405.

USACHPPM (U.S. Army Center for Health Promotion and Preventive Medicine Operational Noise Program) Environmental Noise Study No. 52-34-QK33-95, Results of Eastern Shore Vibration Monitoring, Aberdeen Proving Ground, Maryland, September 1993 - November 1994.

Uncited

AEPI, 1999. Army Environmental Policy Institute, “Army Operational Noise Management Program,” April 1999.

ANSI, 1996. “American National Standard Quantities and Procedures for Description and Measurement of Environmental Sound-Part 4: Noise Assessment and Prediction of Long-Term Community Response,” Acoustical Society of America, New York.

ANSI, 1983. “Guide to the Evaluation of Human Exposure to Vibration in Buildings” (ANSI S3.29-1983). New York: American National Standards Institute, Inc.

Berglund, P. Hassmén, and R. F. S. Job, 1996. “Sources and Effects of Low-Frequency Noise,” Journal of the Acoustical Society of America, 99(5), 2985-3002.

Buchta, E. and J. Kastka, 1982. Relation between the annoyance of traffic noise and physical noise data, Proceedings of Inter-Noise 77, Zurich, 10-3 March 1977, pp.B731-7. as cited in Schultz, T. J. Community Noise Rating, Elsevier Science Publishing Company, New York, NY, 2nd edition.

Cohen, B. H. , Explaining Psychological Statistics, 2nd Ed., John Wiley and Sons, Inc, NY, NY, 2001.

Ellermeier, W., Eigenstetter, M., and Zimmer, K., 2001. “Psychoacoustic correlates of individual noise sensitivity.” J. Acoust. Soc. Am. 109, 1464-1473.

Federal Interagency Committee on Aviation Noise (FICAN). FICAN on the ‘Findings of the Minneapolis-St. Paul International Airport (MSP) Low-Frequency (LFN) Expert Panel,” Published on the FICAN website (www.fican.org), April 2002.

Fidell, S., A. S. Harris, and L. Sutherland, 2000. “Findings of the Low-Frequency Noise Expert Panel of Richfield-MAC Noise Mitigation Agreement of 17 December 1998,” Report to the City of Richfield, Minnesota and the Minneapolis Metropolitan Airports Commission, 2000. (There was not unanimous agreement by the authors on all material in the report).

Fidell, S., Hornonjeff, R., Schultz, T., and Teffeteller, S. 1983. “Community response to blasting,” J. Acoust. Soc. Am. 74(3), 888-893.

Galloway, W.J., 1982. Assessment of Community Response to High-Energy Impulsive Sounds, Report of Working Group 84,Committee on Hearing, Bioacoustics, and Biomechanics of the National Research Council, National Academy of Sciences, Washington, D.C., July 1981, as cited in Schultz, T. J. Community Noise Rating, Elsevier Science Publishing Company, New York, NY, 2nd edition, 1982.

Hodgdon, K.K., Sullivan, B., Atchley, A.A., Solomone, J. “Subjective Perception of Live versus Simulated Sonic Booms,” Report in Progress, 2006.

Hubbard, H. H., 1982. "Noise Induced House Vibrations and Human Perception," Noise Control Engineering Journal, 19(2), 49-55.

Job, R.S.F., 1988. "Community response to noise: A review of factors influencing the relationship between noise exposure and reaction," J. Acoust. Soc. Am. 83, 991-1001.

NASA Langley Research Center, 1978. "Noise–Induced Building Vibrations Caused by Concorde and Conventional Aircraft Operations at Dulles and Kennedy International Airports," Final Report, NASA TM 78769.

Schomer, P. D., 2005, "Criteria for assessment of noise annoyance," Noise Control Engineering Journal, 53(4), July-August 2005.

Schomer, P. D., and J. W. Sias, 1998. "On Spectral Weightings to Assess Human Response Indoors to Blast Noise and Sonic Booms," Noise Control Engineering Journal. 46(2) 57-71.

Schultz, T. J., 1982. Community Noise Rating, Elsevier Science Publishing Company, New York, NY, 2nd edition.

Sharp, B. H., Y. A. Gurovich and W. W. Albee, 2001. "Status of Low-Frequency Aircraft Noise Research and Mitigation," Wyle Research Report WR 01-02.

Siskind, 1989, "Vibrations and Airblast Impacts on Structures from Munitions Disposal Blasts," Proceedings, Inter-Noise 89, G.C. Maling, Jr., editor, pages 573 - 576.

Smith, A., Rich, N., Wilson, S., and Nutt, D., 2001. "Subjective and objective assessment of the effects of noise, noise sensitivity and noise disturbed sleep on health," Inter-Noise 2001.

Ventry, I. M., Schiavetti, N., 1980. Evaluating Research in Speech Pathology and Audiology, John Wiley and Sons, NY, NY.

Zwicker, E. and Fastl, H., 1999. Psychoacoustics Facts and Models, Springer Verlag, New York, New York, 1999.

Appendix: Supporting Technical Data

This Appendix presents technical data and conclusions from research studies of human response to high-energy impulsive noise.

The CHABA (1996) dataset is made up of two sonic boom studies: Oklahoma City reported by Borsky (1965) and NASA reported by Fields et al. (1994), and three blast noise assessment studies: Fort Bragg reported by Schomer (1981), Fort Lewis reported by Schomer (1985), and Sweden reported by Rylander and Lundquist (1996). Figure A-1, taken from directly from CHABA 1996, plots the five datasets in terms of the percent highly annoyed as a function of the yearly averaged metric C-weighted Day-Night Level (CDNL). CHABA concluded that when looking at the entire data set, the correlation between CDNL and annoyance is quite low.

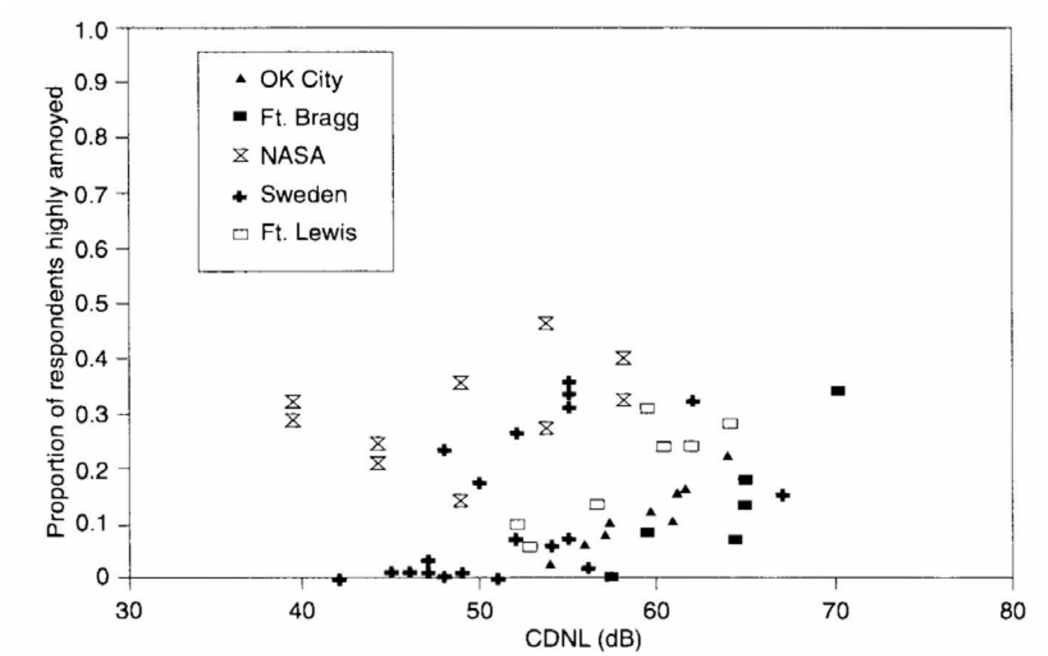


Figure A-1.. Data sets from CHABA 1996.

Oklahoma City Study reported by Borsky (1965). The Oklahoma City sonic boom study consisted of 8,997 interviews that took place during the last 4 months of the 6-month study. During the study, sonic boom flights were carefully controlled and noise measurements were made in terms of peak overpressures for each sonic boom. However, the social survey report (Borsky 1965) did not contain estimates of the sonic boom exposures. In-

stead, ASEL and CSEL measurements were later estimated from the peak overpressure and the lateral distance of the aircraft from the microphone position. These estimated ASEL and CSEL measurements were then combined into A-weighted Day-Night Level (ADNL) and CDNL measurements for the reanalysis included in CHABA 1996 and Fields 1997.

The response to the sonic booms was measured in terms of annoyance on a four-point scale and in terms of interference with six specific tasks: interference with radio or TV, startle or fright, sleep disturbance, house rattle/vibration, interference with rest/relaxation, and interference with conversation.

NASA Study reported by Fields et al. (1994). The sonic boom study conducted by NASA identified two regions in the United States that appeared to have the potential for regular, relatively frequent exposures to sonic booms of at least moderate intensity. A total of 1,573 interviews were completed with 20 sets of community residents (Fields 1997). The interviews were conducted after 6 months of measuring the noise in those areas in terms of CDNL, ADNL, C-weighted 24-Hour Equivalent Level (LCeq24), and LAeq24. Most survey areas were exposed to an average of two booms per day with one boom per week over 2 pounds per square foot (psf), which is approximately equal to a peak level of 134 dB.

Residents reported that the three most disturbing aspects of sonic booms are: being startled, noticing rattles or vibrations, and being concerned about the possibility of damage from the booms. A little over half of the respondents reported that their startle reactions have not lessened from the time when they first heard the booms. Fields also concluded that for this particular data set the importance of how often a boom occurred is under-represented using energy averaging metrics (e.g., CDNL, ADNL, etc.).

Fort Bragg Study reported by Schomer (1981). In 1978, an Army survey was conducted on and around Fort Bragg, NC. Measurements of the stimulus were both predicted and measured. The predicted measurements were reported as a yearly averaged CDNL and were made with computer software that used operational range records from 1 year preceding and following the study. Actual measurements were also made after the study was completed at 17 different locations for an average of 25 days per site. The predicted CDNL used for correlation with the percent of the commu-

nity highly annoyed was slightly lowered because the actual measured results were on the average of 3 to 5 dB lower.

The survey found that there were four primary factors that correlated with annoyance: (1) belief that one should complaint about government activities, (2) sensitivity to noise, (3) belief that more can be done to reduce the noise, and (4) fear that the source will cause damage (Schomer 1981).

<u>Fort Lewis Study Reported by Schomer (1985).</u> A second Army survey was completed during the early 1980's and reported in Schomer 1985. A total of 1,253 residents were surveyed. As in the previous study, measurements of the stimulus were both predicted and measured. The predicted measurements were reported as a yearly averaged CDNL and were made with computer software that used operational range records from 1 year preceding and following the study. Again, actual measurements were made at each of the survey areas, but this time 6 months prior to the survey rather than after the study was completed. However, unlike Schomer's previous study, the actual measurements were not used to modify the predicted CDNL measurement used in the correlation analysis with percent highly annoyed. Schomer reported that the actual noise measurements were inconsistent with the survey results and reported that the attitudinal survey results implied too much annoyance when arrayed against the measured noise data (Schomer 1985).

The major findings of this study were that building rattle was the main adverse blast noise factor and that C-weighting is the best available weighting scale to use because it accounts for the low frequencies that are responsible for causing house vibrations and rattle.

<u>Swedish Study Reported by Rylander and Lundquist (1996).</u> A mail survey was conducted in the vicinity of eight shooting ranges in Sweden. One thousand four hundred eighty-three residents were surveyed. Noise measurements were made by using a computer program that estimated the levels from operational data and assumed propagation over different types of terrains.

The major findings of this study were that blast noise interfered with rest, recreation, and sleep and the effects of were most prominent during the evening and the night (Rylander and Lundquist 1996).

Army Complaint Study Reported by Luz et al. (1983). Noise complaints were gathered from several Army installations over a 1-year time period starting in July of 1979 and ending in June of 1980. Yearly averaged noise measurements for each of the complaint areas were predicted using computer software and operational range data from each of the study sites.

This study found that 77% of the complainants mentioned house vibration or physical damage to their home and concluded that complaints are most likely due to unusual rather than typical noise levels. The study also found that the correlation between complaints and CDNL was very poor (Luz et al. 1983).

An important inference from the above documentation of the failure of CDNL to predict community annoyance is that the equal energy principle does not work when applied to acoustic stimuli over such a large range of noise levels as weapons noise. There is little question that the equal energy principle is an efficient predictor of annoyance for traffic noise, where each day's exposure is to hundreds of sound events. With that many events, the brain fails to retain a memory of individual events (Rylander and Björkman 1988) and only remembers the impression of the general din. In the case of traffic noise, the difference between a large truck passing at 15 feet is about 15 dB higher than the passing of a passenger car at 50 feet. Similarly, the difference between the noisiest and quietest Army helicopters is about 10 dB, and, as demonstrated by Fields and Powell (1987), the equal energy principle does an excellent job at predicting the daily annoyance of helicopter operations as a function of the level and number of overflights (over the range of 1 to 32 flights per day.) For blast noise, however, the modifying effects of meteorological variables result in a sound that, at a distance of 2 miles or more, can vary over a range greater than 40 dB (Schomer et al., 1978). In addition, the sounds are intermittent with a few noisy days interspersed with a larger number of quiet days. With such a broad range of exposures, the simple rules of CDNL fail to mimic subjective experience. Here are a few examples of situations that could contribute to the near zero correlation shown in Figure A-1 above:

- Under the rules of CDNL, a blast occurring at 2205 is treated as if it is 10 dB higher than the same blast at 2155. However, if the subject is asleep at 2205 and the blast is not intense enough to awaken the subject, that blast contributes nothing to the subjective annoyance.

- Under the rules of CDNL, the blast at 2205 contributes as much to the daily dose as ten (10) equally intense blasts at 2155. If the subject happens to be awake at 2155 and notices the blasts inside the home, each event will contribute to the subjective annoyance for that 24 hour period.
- If the low frequency components of the blast signature result in the subject's windows vibrating, the subjective annoyance of a moderately intense blast will be equivalent to a blast without rattle at a level 10 or more dB higher (Schomer and Averbuch 1987). However, this subjective experience cannot be detected in the measurable CDNL.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE (DD-MM-YYYY)
30-10-2007

2. REPORT TYPE
Final

3. DATES COVERED (From - To)

4. TITLE AND SUBTITLE
An Investigation of Community Attitudes Toward Blast Noise: Methodology

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Larry L. Pater, Edward T. Nykaza, George Luz, Anthony Atchley, Kathleen Hodgdon, Robert Baumgartner, and Pamela Rathbun

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Research and Development Center (ERDC)
Construction Engineering Research Laboratory (CERL)
PO Box 9005
Champaign, IL 61826-9005

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/CERL SR-07-24

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Research and Development Center (ERDC)
Construction Engineering Research Laboratory (CERL)
PO Box 9005
Champaign, IL 61826-9005

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

14. ABSTRACT

The military has determined that current blast noise impact assessment procedures do not fully meet the military's noise management needs. Noise impacts are almost universally assessed in terms of the response metric "annoyance" as predicted by a long-term average noise level metric. This has proven to be unsatisfactory for extremely variable impulsive military noise. Individual event noise levels from military testing and training activities can be loud enough to elicit negative community response, and even loud enough to exceed the human hearing damage threshold; yet when events are averaged over a year's time, the average level meets established acceptability criteria.

The objective of this project is to provide a research methodology for improving the current human response to blast noise assessment procedures. More specifically, this report outlines an approach to enhance understanding of human response to blast noise, and to determine a methodology to accurately predict human response to impulsive military noise. This methodology will provide reliable and practicable guidance for noise impact management decisions.

15. SUBJECT TERMS

acoustics	blast noise	training lands
land use planning	noise measurement	sound management

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Edward T. Nykaza
Unclassified	Unclassified	Unclassified	SAR	41	**19b. TELEPHONE NUMBER (include area code)** (217) 352-6511, ext 4561